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GEOCHEMICAL ASSESSMENT AND MODELING OF WATER QUALITY FOR IRRIGATION AND INDUSTRIAL PURPOSES IN OTUOKE AND ENVIRONS, BAYELSA STATE, NIGERIA

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ABSTRACT

The study assesses the geochemistry of water quality for irrigation purposes in Otuoke and environs, Bayelsa State, Nigeria. Assessment of the water quality for irrigation purposes was achieved using models like Sodium adsorption ratio (SAR), Permeability index (PI), Kelly's ratio (KR), Magnesium adsorption ratio (MAR), Sodium percentage and Potential soil (PS) salinity reveals that all the groundwater samples are in excellent condition and can be used for irrigation purposes. Sodium percentage reveals that 14% (2 samples) of the groundwater samples are permissible, while 86% (12 samples) of the groundwater samples are doubtful for irrigation purposes. Magnesium Adsorption ratio reveals that 93% (13 samples) of the groundwater samples are good for irrigation while the remaining 7% (1 sample) is unsuitable for irrigation. Kelly's ratio shows that all the water samples are unsuitable for irrigation. The groundwater in the area shows LSI ranges from -4.34 to -2.24, with a mean of -2.93. Positive Langelier saturation index (LSI) values suggest that water is supersaturated with respect to $CaCO_3$ and scale formation may occur in pipelines and equipment. All groundwater samples have negative Langelier saturation index (LSI) values, which suggest that the groundwater is unsaturated with $CaCO_3$ and fit for industrial usage. The results obtained could serve as a future reference when studying the water quality of Otuoke and its environment.

KEYWORDS

Irrigation, water quality, geochemistry, groundwater, Otuoke.

1. INTRODUCTION

Water is not only essential for life, but also one of the most significant factors in determining the quality of life of humans. Groundwater is one of the most refined forms of water available in nature. It is a valuable natural resource and an important source of water for agriculture and domestic use. Groundwater is a preferred source of drinking water in most developing countries including Nigeria because of its higher quality, and unlike surface water, it is less vulnerable to contamination [1].

The quality of groundwater is of vital concern, since it is directly linked with health and human welfare. In a study clearly stated that the quality of public health depends greatly on the quality of groundwater [2]. Groundwater in the preferred source of potable water in the Niger delta, because it is less prone to contamination as a result of its natural filtration [3]. Although groundwater quality is more preffered when compared to surface water, its quality is the sum of natural and anthropogenic influences [4]. Water quality parameters reflect the level of contamination in water resources and show whether water is suitable for human consumption, irrigation and/or industrial usage. Drinking contaminated water is unacceptable because of its adverse health effects [5].

The quantity of water may not be an issue in a terrain such as Niger Delta but its quality is of utmost importance. A substantial part of the study area is motor able and is close to Yenagoa, the State's capital. This has led to continuous influx of people and increased business activities in the area over the last decade with strong dependence on groundwater. Predominant anthropogenic activities in the area which can pose severe risk to the groundwater resources includes gas flaring from exploitation of oil and gas resources, leakages and corrosion of pipelines, septic tanks and possible effluents from industries, open dumping, etc.

According to World Health Organization, most diseases in human beings are caused by poor quality of water. Pollution of water resources further enhances the multiple problems associated with groundwater and put up more pressure on the difficulty of finding out available fresh water resources. Therefore, this study focuses on the investigation of groundwater quality status for irrigation and industrial use. It is worthy of note that groundwater quality depends on the desired use. The different uses of groundwater require different water quality criteria and standard methods for reporting and comparing groundwater quality results [6]. Therefore, it becomes obligatory to undertake this survey in the area to ascertain its quality for irrigation and industrial purposes.

2. THE STUDY AREA

The study area Federal University Otuoke and its environ is located within the lower section of the upper flood plain deposits of the sub-aerial Niger Delta [7,8]. Geographically, it lies between latitudes 4^0 46'N and 5^0 51'N and longitudes 6^0 15'E and 6^0 23'E (Figure 2). The area is bounded on the North by Yenagoa, the capital of Bayelsa State and on the south by Brass and Nembe local government areas of Bayelsa State, to the West by southern Ijaw and Ahoada-west local government areas of Bayelsa State and Rivers State respectively. The area can be accessed from the north by the Mbiama-Yenagoa road and on the south by the Nembe and Brass Rivers. Most part of the area is motor-able; hence there is a network of roads that links the different parts of the area.

The area lies in the coastal Niger Delta sedimentary basin. The geology of the Niger Delta has been described in detail by various authors. The formation of the Delta started during Early Paleocene and resulted mainly from the buildup of fine grained sediments eroded and transported by the River Niger and its tributaries. The Tertiary Niger Delta is a sedimentary structure formed as a complex regressive off lap sequence of clastic sediments ranging in thickness from 9,000-I2,000m. Starting as separate depocenters, the Niger Delta has coalesced to form a single united system since Miocene. The Niger Delta is a large and ecologically sensitive region, in which various water species including surface and sub-surface water bodies exist in a state of dynamic equilibrium [9]. Stratigraphically, the Niger Delta is sub-divided into Benin, Agbada and Akata Formations in order of increasing age. The geomorphic unit of the Niger Delta is shown in Figure 1.

The Benin Formation is the water bearing zone of the area (Table 1). It is overlain by quaternary deposits (40-I50m thick) and generally consists of rapidly alternating sequence of sands and silty clays with the latter becoming increasingly more prominent seawards [10]. The clayey intercalations within the Benin formation have given rise to multi-aquifer system in the area [10-12]. The first aquifer is commonly unconfined while the rest are confined. The study area has been noted to have poor groundwater quality due to objectionable high concentration of certain groundwater parameters and encroachment of saltwater or brackish water into the freshwater aquifers [13]. The static water level in the area ranges from 0-2m during the rainy season and I-3m during the dry season [14]. The main source of recharge is through direct precipitation where annual rainfall is as high as 3000mm [15]. The water infiltrates through the highly permeable sands of the Benin Formation to recharge the aquifers. Groundwater in the area occurs principally under water table conditions [16].

Table 1: Geologic units of the Niger Delta [10]

Geologic Unit	Lithology	Age
Alluvium	Gravel, Sand, clay, silt	Quaternary
Freshwater Backswamp, meander belt	Sand, clay, some silt, gravel	
Saltwater Mangrove swamp and back-swamp	Medium-fine sands, clay and some silt	
Active/abandoned beach ridges	Sand, clay, and some silt	
Sombreiro-Warri deltaic plain	Sand, clay, and some silt	

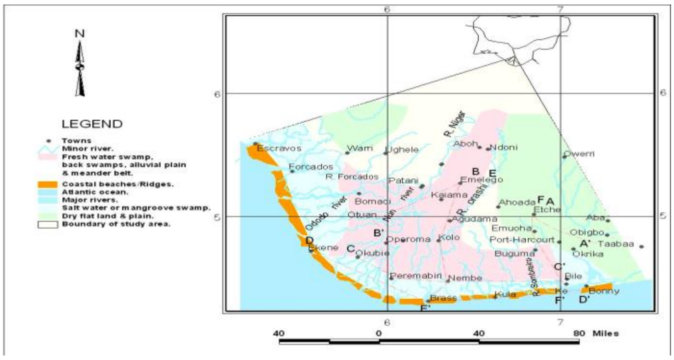

Figure 1: Geomorphic units of the Niger Delta [7].

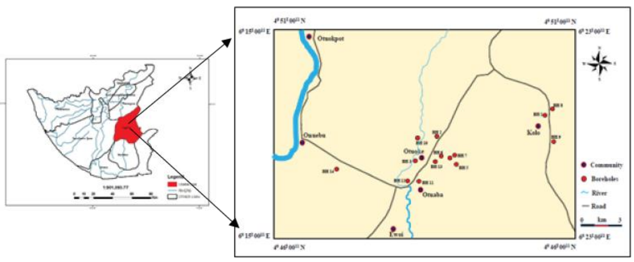

Figure 2: Map of Bayelsa State showing the study area and sample locations

3. METHODS OF STUDY

Groundwater samples were collected from fourteen (14) boreholes in Federal University of Otuoke and its environs during the rainy season. The boreholes utilized for this study were selected from eight communities at random. Both private and public water sources were sampled in this study. Standard sampling and analytical methods were used in the study. The laboratory results are shown in Table 1. Various indices were used to determine the quality of groundwater for irrigation in the study area. The various indices are discussed in the following sub-headings.

3.1 Sodium Adsorption Ratio (SAR)

The SAR was calculated after Richards theory as follows [17]:

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \quad (1)$$

All parameters are in meq/L.

3.2 Magnesium Adsorption Ratio (MAR)

The MAR was calculated after Raghunath theory as follows [18]:

$$MAR = \frac{Mg}{Ca + Mg} \times 100 \quad (2)$$

All parameters are in meq/L.

3.3 Kelly's Ratio

The KR was calculated after a group researchers theory as follows [19]:

$$KR = \frac{Na}{Ca + Mg} \quad (3)$$

All parameters are in meq/L.

3.4 Sodium Percentage (Na%)

The Na% was calculated after Wilcox as follows [20]:

$$Na\% = \frac{Na}{Na + Ca + Mg + K} \times 100 \quad (4)$$

All parameters are in meq/L.

3.5 Permeable Index (PI)

The PI was calculated after Doneen as follows [21]:

$$\left(\left|\left(Na^{+} + \sqrt{HCO_3^{-}}\right)\right| \div \lfloor\left(Ca^{2+} + Mg^{2+} + Na^{+}\right)\rfloor\right) \times 100 \quad (5)$$

All parameters are in meq/L.

3.6 Potential Salinity (PS)

The PS was calculated after Doneen as follows [22]:

$$PS = Cl^{-} + \sqrt{SO_4^{2-}} \quad (6)$$

All parameters are in meq/L.

4. RESULTS AND DISCUSSION

Table 1: Results of physicochemical and heavy metals in groundwater from the study area

Parameters	Units	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11	BH12	BH13	BH14
		Kolo 1	Otuoke1	Otuoke2	Fuo 1	Fuo 2	Fuo 3	Fuo 4	Kolo 2	Kolo 3	Eferiwo	Otuaba	Abaye	Elabio	Obruba
Temperature	^{0}C	27.50	27.10	27.30	27.20	27.30	27.2s0	27.10	29.50	28.20	25.90	24.60	27.40	28.30	27.70
pH		6.31	6.52	4.98	6.71	6.53	6.21	7.01	6.83	5.76	6.72	6.90	5.73	6.22	6.77
Conductivity	µS/cm	53.20	118.70	96.30	73.00	75.00	90.50	83.60	120.40	130.30	81.30	98.40	94.50	87.70	124.50
Turdidity	NTU	3.75	4.73	4.16	5.00	5.14	3.71	4.77	3.99	4.55	4.21	4.75	3.88	4.55	4.29
TSS	mg/L	10.60	6.27	13.01	12.75	4.72	5.89	5.99	4.73	12.01	6.77	8.91	11.11	13.02	10.02
TDS	mg/L	22.82	13.51	27.56	12.75	33.55	21.06	4.11	68.00	92.10	53.50	40.10	36.30	40.57	38.30
Chloride	mg/L	23.89	26.71	14.33	15.74	19.51	41.31	25.04	23.90	19.30	16.03	17.89	39.33	47.80	31.51
Bicarbonate	mg/L	3.00	0.40	1.60	0.90	0.80	0.90	1.94	1.60	0.92	2.50	1.20	4.80	1.60	0.90
Hardness	mg/L	51.00	32.00	35.00	37.00	39.00	50.00	61.00	49.00	37.00	32.00	39.00	53.00	50.00	46.00
Calcium	mg/L	25.00	23.10	28.31	26.02	24.10	23.03	26.40	29.01	29.01	28.10	30.01	14.99	55.03	44.41
Magnesium	mg/L	7.82	9.33	9.91	8.88	8.30	7.91	8.33	11.12	11.12	13.14	11.01	15.05	7.93	10.22
Sulphate	mg/L	0.09	0.03	0.05	0.06	0.03	0.07	0.04	0.09	0.09	0.03	0.02	0.01	0.06	0.07
Phosphate	mg/L	5.01	0.03	0.06	0.01	0.02	0.07	0.05	0.21	0.21	0.04	0.05	0.07	0.04	0.01
Alkalinity	mg/L	10.90	10.83	10.44	11.02	12.01	11.05	11.02	11.60	11.60	10.34	11.00	11.08	11.88	11.92
Iron	mg/L	0.07	0.11	1.25	10.00	0.11	0.56	0.00	0.09	0.12	0.32	0.12	0.06	0.01	0.41
Nitrate	mg/L	0.07	0.20	0.10	0.06	0.03	0.04	0.01	0.03	0.02	0.05	0.03	0.11	0.21	0.15
Sodium	mg/L	100.00	102.00	111.00	103.00	93.00	112.00	96.00	100.00	101.00	101.00	103.00	102.00	102.00	98.00
Manganese	mg/L	0.01	0.12	0.15	0.16	0.11	0.10	0.15	0.10	0.91	0.12	0.10	0.15	0.17	0.12
Potassium	mg/L	4.20	1.47	1.55	0.76	1.20	1.43	4.65	1.80	2.62	2.50	1.80	2.25	2.13	4.00
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	0.01	0.003	0.002	0.006	0.035	<0.001	0.021	0.011	<0.001	0.013	0.01	<0.001	<0.001	<0.001
Barium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.0012	<0.001	<0.001	<0.001	<0.001	0.0012	0.0011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 2: Results of groundwater quality models for irrigation purposes

Borehole	SAR	NA %	PI	MAR	KR	PS
BH1	4.46	70.09	73.12	34.27	2.29	0.73
BH2	4.51	69.83	70.92	40.23	2.29	0.79
BH3	4.56	68.46	70.58	36.85	2.15	0.45
BH4	4.43	68.79	70.56	36.26	2.19	0.49
BH5	4.15	68.23	70.00	36.47	2.13	0.58
BH6	5.12	73.04	74.71	36.40	2.69	1.22
BH7	4.16	68.07	70.33	34.46	2.07	0.75
BH8	3.99	64.89	67.06	38.98	1.83	0.73
BH9	4.03	65.22	66.69	38.98	1.85	0.60
BH10	3.93	64.06	66.66	43.80	1.76	0.49
BH11	4.07	65.17	66.97	37.94	1.85	0.53
BH12	4.43	69.16	73.24	62.59	2.21	1.13
BH13	3.40	56.82	58.58	19.37	1.30	1.40
BH14	3.44	58.68	59.76	27.72	1.39	0.94
Minimum	3.40	56.82	58.58	19.37	1.30	0.45
Maximum	5.12	73.04	74.71	62.59	2.69	1.40
Mean	4.19	66.46	68.51	37.45	2.00	0.77
SD	0.45	4.43	4.71	9.32	0.37	0.29

Table 3: Results interpretation of the various groundwater quality models for the study area

Classification scheme	Categories	Range (mg/L)	Percent of Samples	Number of samples
Sodium adsorption ratio (SAR)	Excellent	<10	100	14
	Good	10-18	0	Nil
	Fair	>18-26	0	Nil
	Poor	>26	0	Nil
	Hard	>200-300	0	Nil
	Very hard	>300	0	Nil
Sodium Percentage (Na%)	Excellent	up to 20	0	Nil
	Good	>20-40	0	Nil
	Permissible	>40-60	14	2
	Doubtful	>60-80	86	12
	Unsuitable	>80	0	Nil
Permeability Index (PI)	Excellent	> 75	0	Nil
	Good	25-75	100	14
	Unsuitable	< 25	0	Nil
Magnesium adsorption ratio (MAR)	Acceptable	<50	93	13
	Non-acceptable	>50	7	1
Kelly's ratio	Suitable	<1	0	Nil

(KR)	Unsuitable	>1	100	14
Potential soil salinity (PS)	Excellent to good	<5	100	14
	Good to injurious	5-10	0	Nil
	Injurious to unsatisfactory	>10	0	Nil

4.1 Suitability for Irrigation Purposes

The suitability of groundwater for irrigation purposes was achieved using the following water quality models; EC, Sodium Adsorption Ratio (SAR), Salinity potential (PS), Permeability Index (PI), Percent sodium (Na %), Kelly's Ratio (KR), and Magnesium Adsorption Ratio (MAR).

4.2 Sodium Adsorption Ratio (SAR)

The SAR ranges from 3.40 to 5.12, with a mean and SD of 4.19±0.45 (Table 2). Based on a researcher classification scheme, all the samples have SAR values < 10 (Table 3) [17]. This is an indication that the Groundwater is in excellent condition and can be used for agricultural purposes. Salinity classification was done using a quality diagram (Figure 3a and 3b) proposed by the US Salinity Laboratory [23]. The diagram has 16 classes, with reference to SAR as an index of sodium hazard and EC as an index of salinity hazard.

By plotting the obtained results from this study on the diagram (Figure 4), all the groundwater samples fell into the "C1-S1" category, which classes the water as having low salinity and low sodium hazard, an indication that the water can be safely utilized for irrigation purposes.

4.3 Sodium Percentage (Na%)

The results of sodium percentage range from 56.82 to 73.04%, with mean and SD of 44.46±4.43% (Table 2). In high concentrations, sodium reacts with soil and decreases its overall permeability. Based on a study, a classification scheme for the groundwater in the area as shown in Table 4, twelve samples are classed as having doubtful composition for irrigation, while two samples have permissible composition for irrigation purposes [20].

On the diagram which classifies water for irrigation based on a plot of sodium percentage versus conductivity, the groundwater samples all plots in the field of excellent to good water for irrigation purposes (Figure 3a & 3b) [20]. The close proximity of some of the samples to the boundary suggests that there may have permissible to doubtful composition.

4.4 Kelly's Ratio (KR)

The results of KR range from 1.3 to 2.69, with mean and SD of 3.0±0.37 (Table 2). KR greater than 1 shows an excess of sodium, and KR less than 1 signifies its deficit in water [24]. All the groundwater samples have KR values above 1 (Table 2), indicating that groundwater in the area is unfit for irrigation.

4.5 Magnesium Adsorption Ratio (MAR)

Calcium and Mg maintains a state of equilibrium in most water. More Mg in water will adversely affect crop yields, as the soils becomes more saline [25]. The MAR in this study ranges from 19.37 to 62.59%, with mean and standard deviation of 37.45±9.32% (Table 3). According to a study, groundwater with MAR < 50% are acceptable, while values > 50% are unsuitable for irrigation [26]. The results obtained from this study shows that majority of the groundwater samples have MAR values below 50% (Table 3), indicating that they are acceptable for irrigation purposes. Only BH12 had MAR (62.59%) which exceeded 50%, hence, unsuitable to be used as irrigation water.

4.6 Permeability Index (PI)

The PI for groundwater in the area ranges from 58.58 to 74.71%, with mean and SD of 68.51±4.71% (Table 2). According to classification of PI, all the groundwater samples are within the range of 25-75% (Table 2), which indicates that they are good for irrigation purposes [21]. A high permeability index enhances crops yield because the soils becomes more aerated and allows flow to occur easily, carrying plant nutrients from one part of the soil to the other.

4.7 Salinity Potential (PS)

The PS ranges from 0.45 to 1.40, with mean and SD of 0.77±0.29 (Table 2). According to classification based on PS, all the groundwater samples have PI values below 5, indicating that they can be safely utilized for irrigation purposes (Table 2) [22]. High PS values damages soil, and generally reduces crop yield.

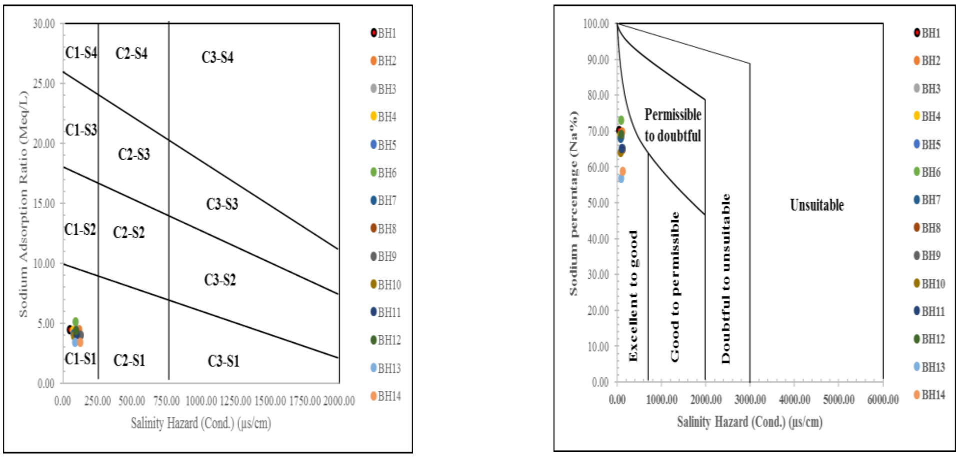

Figure 3: a) Classification with respect to SAR and salinity hazards; b) Classification based on Wilcox diagram [20]

4.8 Suitability for Industrial Purposes

Water is considered safe for industrial use if it is neither scale-forming nor scale-removing in nature. Langelier saturation index (LSI) is the most widely used indicator of cooling water scale potential [27]. The groundwater in the area shows LSI ranges from -4.34 to -2.24, with a mean of -2.93. Positive LSI values suggest that water is supersaturated with respect to $CaCO_3$ and scale formation may occur in pipelines and equipment [28]. All groundwater samples have negative LSI values, which suggest that the groundwater is unsaturated with $CaCO_3$ and fit for industrial usage.

Based on American Water Works Association guidelines for industrial waters, the mean pH values render the groundwater in the area unfit for industrial use except otherwise treated (Table 4) [29-34]. All other quality indicators are within regulatory guidelines.

Table 4: Comparing mean parameters with America Water Works Association guidelines for water use in the Industry [29]

Parameters	Units	Mean	AWWA(1971)
pH		6.37	6.5-8.3
TDS	Mg/l	36.02	500-1500
Hardness	Mg/l	43.64	0-250
Cl	Mg/l	25.88	20-250
Fe	Mg/l	0.95	0.1-1
Mn	Mg/l	0.18	0-0.5

5. CONCLUSION

Assessment of the water quality for irrigation purposes was achieved using models like SAR, PS, PI, Na %, KR, and MAR. Sodium adsorption ratio, Permeability index, Kelly's ratio and Potential soil salinity reveals that all the groundwater samples are in excellent condition and can be used for irrigation purposes. Sodium percentage reveals that 14% (2 samples) of the groundwater samples are permissible, while 86% (12 samples) of the groundwater samples are doubtful for irrigation purposes. Magnesium Adsorption ratio reveals that 93% (13 samples) of the groundwater samples are good for irrigation while the remaining 7% (1 sample) is unsuitable for irrigation. Kelly's ratio shows that all the water samples are unsuitable for irrigation.

The groundwater in the area shows Langelier saturation index(LSI) ranges from -4.34 to -2.24, with a mean of -2.93. Positive LSI values suggest that water is supersaturated with respect to $CaCO_3$ and scale formation may occur in pipelines and equipment. All groundwater samples have negative LSI values, which suggest that the groundwater is unsaturated with $CaCO_3$ and fit for industrial usage. The results of this study could serve as a future reference when studying the water quality of Otuoke and its environment for agricultural planning.

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